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Measuring Climate Change Impact on Urban Microclimate: a Case Study of Concepción

Irina Tumini[a]*, Carlos Rubio-Bellido[b]

[a]*Planning and Urban Design Department, Faculty of Architecture, Construction and Design, Universidad del Bío-Bío, Avd. Collao 1202, 4081112 Concepción, Chile.*
[b]*Department of Building Science, Faculty of Architecture, Construction and Design, Universidad del Bío-Bío, Avd. Collao 1202, 4081112 Concepción, Chile*

Abstract

Cities, due to the concentration of population, economic activities and built infrastructures, are high-risk and potential damage areas in global warming scenarios. Specific climate conditions, which occurs in urban areas, are expected to change with almost certainly disadvantageous effects on quality of life at outdoor spaces. This paper presents an evaluation of climate change impact on cities, by simulating the thermal performance of outdoor spaces, using different climate scenarios. The Plaza de Armas of Concepción (Chile) has been used as case study, and climate conditions at 2020, 2050 and 2080 have been produced for the acknowledged A2 'medium-high' emissions Greenhouse Gases GHG scenario, according to Intergovernmental Panel on Climate Change IPCC. To simulate the urban microclimate, the ENVI-met v4 software, a three-dimensional numerical model based primarily on fluid dynamic and thermodynamic models has been used to estimate interaction between surfaces, plant and atmosphere at the micro-scale. The comparison between different scenarios and discussion about results are presented as well. The results and discussion are a first step to advance on the knowledge of climate change impact for proposing adaptation strategies in the urban context.

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Keywords: climate change; climate adaption; urban microclimate; Microclimate simulation; CFD; Chile;

* Corresponding author. Tel.: +56 413111806; fax: +56 413111806.
E-mail address: irina.tumini@gmail.com

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1. Introduction

Cities, due to rapid growing and the concentration of population are especially vulnerable to climate change impact. Due to this fact, it is acknowledged the necessity to concentrate efforts in adaptation strategies in cities to face new weather conditions caused by global warning. Climate change scenarios suggest average annual temperature may increase by between 1ºC and 5ºC by 2080s, with an increase in summer temperature more significant than in winter. Urban areas are generally influenced by Urban Heat Island (UHI) effect, which means an increase of temperature with regard to their surroundings. Thus, climate change would significantly impact in urban microclimate than expected in rural areas[1]. The intensity of UHI effect varies in time and space as result of meteorological, location and urban characteristics [2,3] Urban morphology, soil materials, anthropogenic emissions and vegetation have an influence on the environmental performance at micro-scale.

Numerous are the studies that consider global warming, increase of emissions and scarcity of natural resources since the creation of the Intergovernmental Panel on Climate Change (IPCC) in 1988, which has recently published its Fifth Assessment Report (AR5) [5]. In this line, sundry prediction models have been generated for various climate scenarios. Currently, IPCC, supported by United Nations Environment Programme (UNEP) and World Meteorological Organization (WMO), which is the most widely accepted organization in this matter, envisages multiple emission scenarios [6] for the near future (years 2020, 2050 and 2080). Jentsch et al. [7] concluded that morphing actual weather files in format EnergyPlus/ESP-r Weather (EPW) with previsions from IPCC using HadCM3 files for the scenario A2 gives a consistent base to calculate variations in energy demand for buildings. Other authors have also made significant contributions on the technical aspects of the morphing process of weather files [8,9], giving a reliable technical base to undertake this research.

The aim of this paper is advance in the knowledge of urban microclimate creation and appraises its impact in climate change scenarios. Environmental uncertainties pose new challenges to planners, which should use different approaches for cities adaptation. The actual need for policies oriented towards climate change mitigation is a key role for reducing urban vulnerability and enhancing cities adaptation.

2. Numerical models

2.1. Climate Change Forecasting

Weather data files are obtained by Meteornom ® (Table 1). The data are exported to EnergyPlus Weather (EPW) format. This file has been used for model called "current", whose data files comprise average values for the period 1960-1991. Future scenarios have been modelled taking into account the suitability of the model UK Met Office Hadley Centre Coupled Model 3 HadCM3 [10] and which takes into account the combination of A2a, A2b and A2c patterns. Through the CCWorldWeatherGen program [11], based on the studies of Belcher et al. [12], EPW file for the base scenario is "morphed" with the GHG A2 emissions scenario, obtaining data for the years 2020, 2050 and 2080 (Table 1).

2.2. Description of ENVI-met model

Advances on computer resolution capacity allows adding complexity to non-linearity urban climate models. Numerical simulations have the advantage of perform and compare multiple iterations in order to provide better solutions for improving local microclimate [13,14].

There are different approaches to simulate urban climate; which differ substantially according to their physical context and their temporal and spatial scale [15,16]. The most used at neighbourhood scale (micro-scale) is the Computational Fluid Dynamic approach (CFD) that allowed simulate energy and flow distribution between atmosphere and surfaces. Among the current software, ENVI-met runs a three-dimensional non-hydrostatic model developed to simulate the state of atmosphere taking into account the influence of buildings, surfaces, vegetation, soil characteristics and climate contour conditions [13,17,18]. The last version of ENVI-met (v4.0) considers atmospheric temporal variation and consequently, a better characterization of real conditions with regard to the daily temperature variation. Thanks to this new improvement, it is possible to simulate future climatic scenarios conditions, assessing the impact of climate change within urban environment.

Table 1. Average environmental parameters in Concepción. Current and A2 GHG scenarios for 2020, 2050 and 2080.

Parameter	Year	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Air Temperature (ºC)	Current	13.0	17.0	16.6	15.4	13.2	11.3	9.7	9.2	10.1	10.8	12.3	14.2	16.0
	2020	13.7	18.0	17.5	16.0	14.0	11.9	10.4	9.9	10.9	11.5	12.9	14.9	17.0
	2050	14.4	19.0	18.2	16.8	14.6	12.4	10.7	10.4	11.5	12.1	13.6	15.6	17.9
	2080	15.6	20.1	19.5	18.3	16.0	13.6	11.8	11.3	12.2	13.0	14.7	16.8	19.3
Relative Humidity (%)	Current	81.9	74.1	76.5	79.2	87.9	88.3	88.4	85.8	83.6	80.5	83.3	78.0	77.7
	2020	81.3	74.1	77.4	79.2	88.0	87.3	87.4	84.8	82.6	79.5	82.3	76.0	76.7
	2050	80.4	72.1	76.4	80.1	87.0	86.3	86.4	84.9	82.5	78.5	81.3	75.0	74.7
	2080	79.1	71.1	75.4	78.2	86.0	85.3	86.4	82.8	80.6	77.5	80.3	73.0	72.7
Global Horizontal Radiation (Wh/m^2)	Current	355	537	507	405	307	189	162	182	236	335	414	467	520
	2020	358	540	506	405	306	193	166	184	239	342	420	475	525
	2050	361	539	500	400	310	195	173	188	244	346	423	477	531
	2080	366	537	504	409	314	201	177	193	249	353	437	485	534

3. Methodology

3.1. Description of Case Study

3.1.1. Current and future climate

The case study analysed in this research is the Plaza de Armas square in Concepción, Chile. Concepción is located at 36º 50’ S and 73º 03’ W, with an average elevation about 12m. The regional climate is Mediterranean with oceanic influence by means of Köppen classification.

Air temperature rarely exceed 30ºC or fall below 0ºC with an annual average of 13.0ºC. Due to climate change, air temperature will increase 2.6ºC (Table 1), being more pronounced during summer periods. Relative humidity tends to reduce from the average annual percentage of 81.9% to 79.1%. Global Horizontal Radiation will scarcely increase according to IPCC.

a) b)

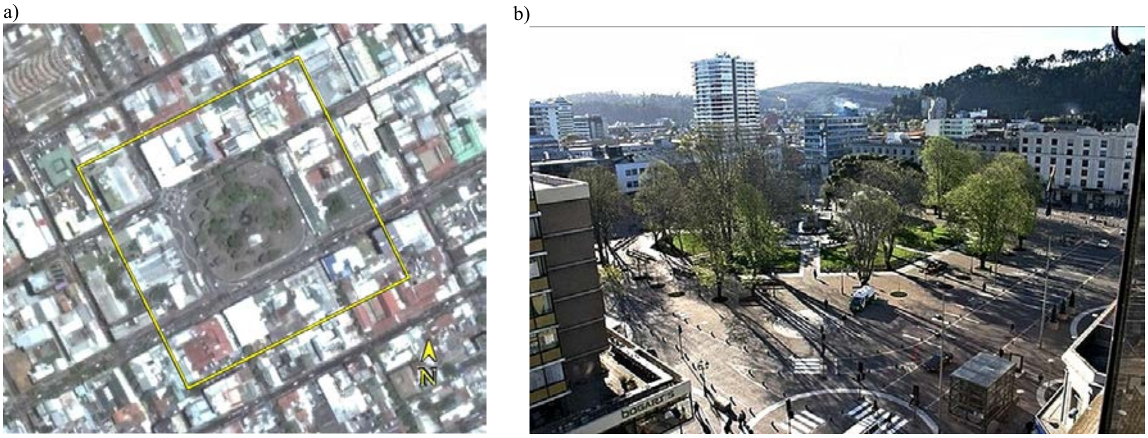

Fig. 1. a) Aerial view and b) picture of Plaza de Armas square. Source: Google, DigitalGlobe, 2016.

3.1.2. The urban morphology

The Plaza de Armas is a square located in the city centre, with square form following the regular grid of downtown. The square is characterized by a circular fountain in the centre and green spaces with tall trees along the perimeter, the pedestrian space use grey concrete as soil. Buildings that surround the square are different in morphology and height: from 2 floors to 12 floors (Fig.1). The square is located in an important commercial area of the city; it is an emblematic space for citizen social cohesion. The morphology, materials and current use of the square are remarkably similar to others in Chile [19], representing the first meeting-point for the city. For this reason, Plaza de Armas has been chose as representative case study to evaluate climate change impact on urban microclimate.

3.2. Model evaluation

To evaluate the impact of climate change at urban scale, a 3D model has been modelled and simulated in different climate scenarios. The 3D model domain was defined according to real morphology of Plaza de Armas and capacity of system, with horizontal dimension equal to 240x240m, discretized in regular 3x3m grid.

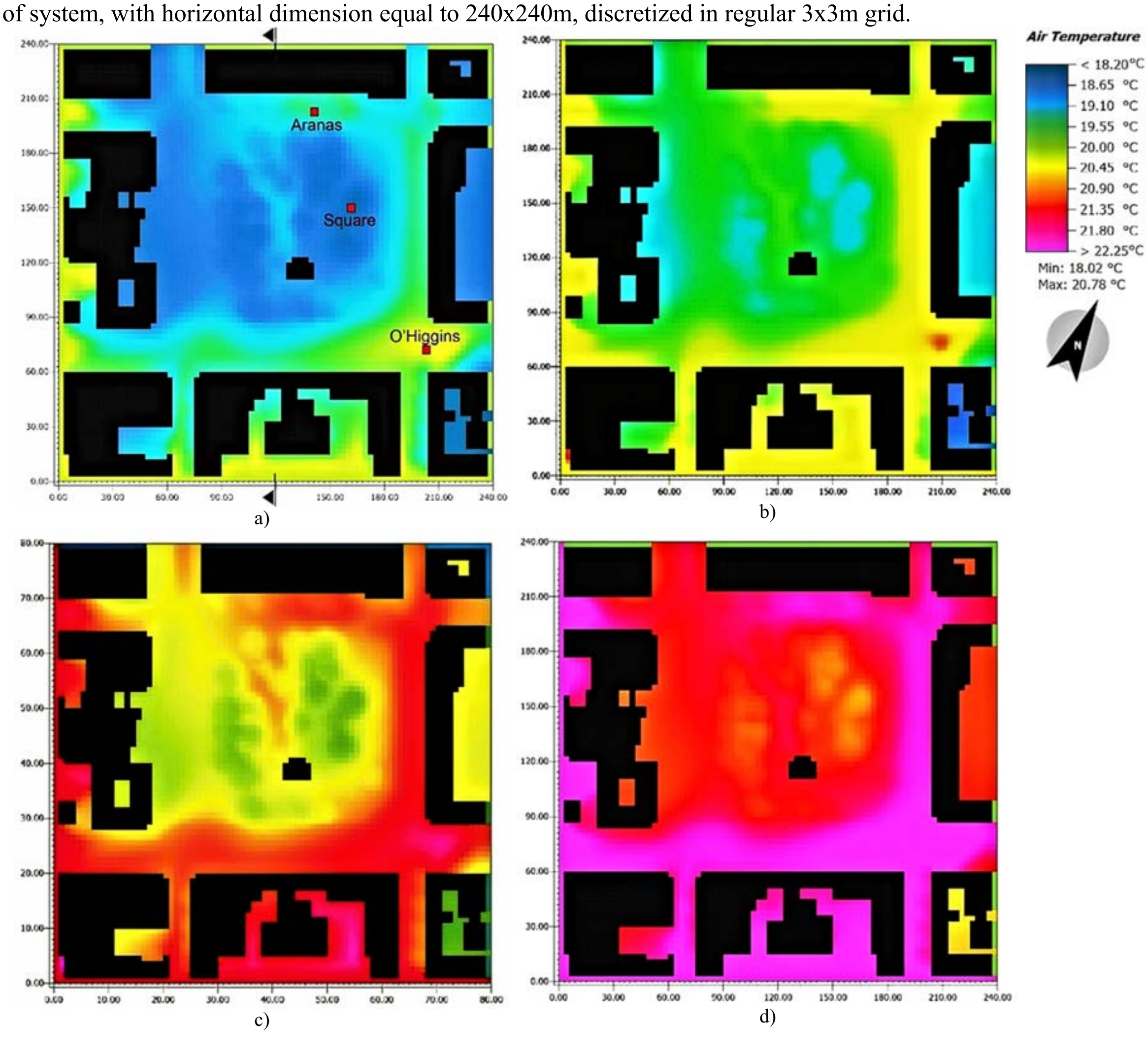

Fig. 2. Result of simulation, air temperature map, horizontal view (a) Current state, with indication of the three station and vertical section; (b) 2020 scenario; (c) 2050 scenario; (d) 2080 scenario.

The vertical domain was established equidistant with 0.4m vertical grid size for the 5 lowest grid cell, and 3m for the others. CFD simulations were carried out at 00:00 local time (i.e. UTC-3) during 24h, obtaining thermal performance during a representative day in summer, which coincides with a high average of air temperature, that is, 15th January.

4. Results and Discussions

The results of CDF simulations show different thermal condition in the area, more significant between the square and pedestrian streets and those streets with vehicular traffic such as O'Higgins and Anibal Pinto Street. The square presents lower temperatures due to the presence of green spaces, especially tall trees, which provide shading and temperature mitigation thanks to evapotranspiration. While road streets, with black surface materials, show higher temperatures due to heat storage, more significant in summer (Fig. 2a). The thermal differential ΔT into the simulated area are about 2ºC and the daily thermal heat wave is around 8.4ºC in Barros Arana street, 6.8 ºC in the square and 9.3 in O'Higgins street (Table 2).

Table 2. Comparison of air temperature (T ºC) obtained by simulating microclimate conditions in urban environment for Current state, 2020, 2050 and 2080 climate scenarios.

Loc.	Scenario	Hour																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Barros Arana Street	Current	13.8	13.1	12.6	12.1	11.7	11.5	11.7	12.6	13.7	15.1	16.3	17.5	18.5	19.4	19.8	19.7	19.4	18.8	18.1	17.2	16.5	15.8	15.1	14.3
	2020	14.7	14.1	13.5	13.0	12.6	12.4	12.6	13.9	15.0	16.3	17.5	18.7	19.6	20.3	20.7	20.7	20.4	19.8	19.0	18.4	17.6	16.9	16.2	15.4
	2050	15.3	14.6	14.0	13.5	13.0	12.8	13.0	13.9	15.1	16.5	17.9	19.2	20.3	21.1	21.5	21.6	21.4	20.8	20.0	19.2	18.4	17.7	16.9	16.0
	2080	16.3	15.6	15.1	14.6	14.2	14.0	14.2	15.1	16.3	17.7	18.9	20.2	21.2	22.0	22.4	22.5	22.2	21.7	20.9	20.0	19.3	18.6	17.9	17.1
Plaza de Armas Square	Current	13.5	12.8	12.3	11.8	11.4	11.2	11.5	12.4	13.3	14.3	15.3	16.4	17.3	18.3	18.7	18.7	18.6	18.2	17.5	16.8	16.1	15.5	14.8	14.0
	2020	14.4	13.8	13.2	12.7	12.4	12.1	12.4	13.6	14.5	15.5	16.5	17.5	18.4	19.1	19.6	19.7	19.6	19.2	18.5	18.1	17.3	16.5	15.8	15.0
	2050	15.1	14.4	13.8	13.3	12.9	12.7	12.9	13.8	14.9	16.0	17.0	18.2	19.2	20.1	20.6	20.7	20.6	20.3	19.6	18.9	18.2	17.4	16.7	15.8
	2080	16.1	15.4	14.9	14.4	14.0	13.8	14.1	15.0	15.9	17.0	18.0	19.1	20.1	20.9	21.4	21.5	21.4	21.1	20.4	19.6	19.0	18.3	17.6	16.8
O'Higgins Street	Current	13.2	12.4	11.9	11.4	11.0	10.7	11.1	12.0	13.4	15.0	16.5	17.9	19.1	20.2	20.5	20.3	20.0	19.3	18.4	17.3	16.5	15.7	14.8	13.8
	2020	14.1	13.3	12.8	12.2	11.8	11.6	12.0	13.3	14.5	16.0	17.4	18.8	19.9	20.7	21.1	21.1	20.9	20.2	19.3	18.7	17.6	16.7	15.8	14.8
	2050	14.8	13.9	13.3	12.8	12.3	12.1	12.4	13.5	14.9	16.6	18.1	19.7	20.9	21.8	22.2	22.2	21.9	21.3	20.3	19.2	18.4	17.4	16.5	15.5
	2080	15.8	15.0	14.5	13.9	13.5	13.3	13.7	14.7	16.1	17.7	19.2	20.7	21.9	22.8	23.2	23.2	22.9	22.3	21.3	20.2	19.4	18.5	17.6	16.6

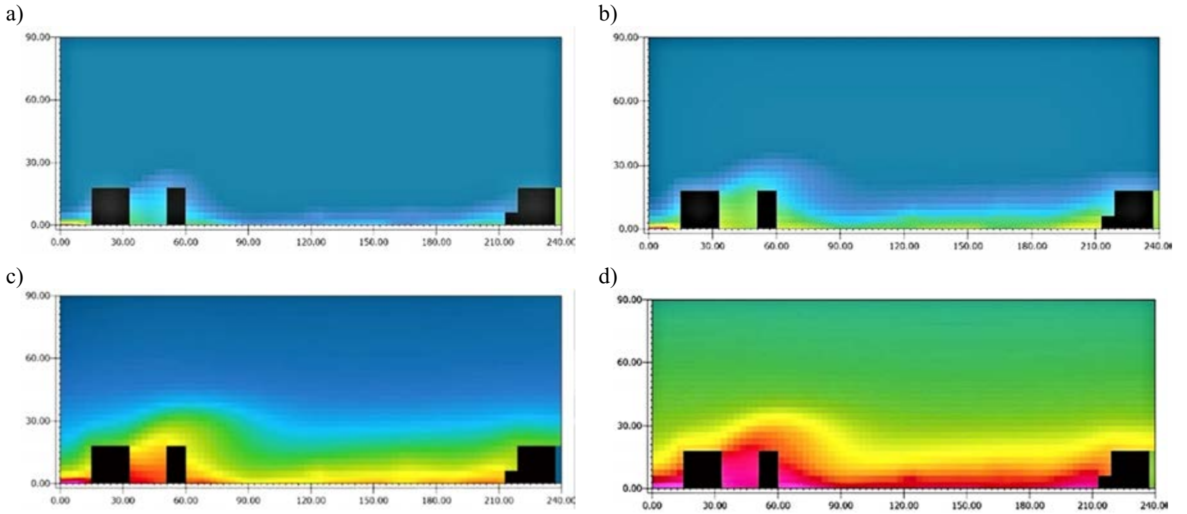

Fig. 3. Result of simulation, air temperature map, vertical section view (a) Current state; (b) 2020 scenario; (c) 2050 scenario; (d) 2080 scenario.

By comparing initial meteorological data (from Carriel Sur Airport measurement) and the simulation results, the effect of urban environment on climate at the micro-scale can be summarised in a temperature increase, more significant during the night, and a reduction in relative humidity and wind speed. This means that the urban microclimate creates by typical square-grid morphology is characterized by the decrease of daily temperature amplitude and reduction of wind speed, that usually promote heat dispersion during the night. The same behaviour is maintained in the other scenarios.

By comparing the scenarios of each other, the increase of temperature is the most significant result. With regard to the current state, the simulations results show an increment in average temperature around 1.02ºC, 1.60ºC and 2.70ºC for 2020, 2050 and 2080 scenarios, respectively. The average relative humidity reduction is equal to 0.91%, 2.89% and 4.11% for 2020, 2050 and 2080, respectively.

Vertical sections provide interesting results about air temperature behaviour in both square and urban canyons. The result of current state (Fig. 3a), shows lower temperature near the soil in the square area. In the 2020, 2050 and 2080 scenarios, the temperature increase, not only at ground level, but also at upper levels with more intensity. The most significant change is produced into urban canyon: comparing current conditions and 2080 scenario, the difference of temperature is around 3ºC at soil level and 3.30-3.45ºC up to roof level (15m). This advises that in addition to the increase of temperature, the built environment produce a heat storage effect, thus amplifying unfavourable conditions in urban areas.

5. Conclusions

This research quantifies the impact of climate change on urban environment and especially on typical urban morphology of Latin-American cities by means of modelling and CDF simulations. Future climate scenarios will affect urban environment increasing temperature and reducing moisture in outdoor spaces. At ground level, unfavourable thermal conditions influences on whether to use or not the public space. Moreover, changes on temperature distribution between soil and the top of buildings, will affect the heat exchange between air and buildings. Simulation results highlight the mitigation effect produced by green areas: the temperature difference between green areas (Square) and the street (O'Higgins) in each scenario is around to -2ºC at 2 p.m. (max temp.) and around +1ºC at 5 a.m. (min temp.). In addition, the heat storage into urban canyon suggests that mitigation measures should to be oriented toward reducing heat gains in summer, for instance by providing shading systems. The implementation of passive strategies at urban level will outcome urban quality betterment as well as energy saving.

This research is an approximation to the urban space adaptation to climate change; further studies should be conducted in order to improve the understanding on climate change impact on urban microclimate.

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